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THE EFFECT OF CRYOGENIC TEMPERATURES ON VARIOUS COMMERCIAL BATTERIES

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John D. Hoyt

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INDIAN HEAD, MARYLAND 20640

C. K. NAYLOR
CAPTAIN, USN
Commanding Officer

LIONEL A. DICKINSON
Technical Director

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ABSTRACT

Many Improvised Explosive Devices (IED's) are fired by discharging electricity from a battery directly into an electric detonator. The purpose of this study was to determine if one possible method for defeating these type IED's would be to cool the batteries to cryogenic temperatures. Only those batteries readily available to the general public were investigated.

INTRODUCTION

Many Improvised Explosive Devices (IED's) are fired by discharging electricity from a battery directly into an electric detonator. One possible method of defeating these IED's is cooling them to cryogenic temperatures. This cools the batteries until they can no longer produce sufficient power to fire the detonator.

It was the purpose of this study to determine how quickly various batteries at room temperature (23.9° C) become inactive after being totally immersed in a bath of liquid nitrogen (-195.1° C). Only batteries that are easily available to the general public were investigated.

TESTS CONDUCTED

From a search of the available information, it was found that electric detonators require at least several hundred milliwatts of power to fire. Thus it was decided that, for an adequate safety margin, a battery was "dead" when it could not produce a 1-milliamphere current through a 2-ohm load. The following battery types were tested: (1) Zn-C 1.5-volt AA cells; (2) Alkaline 1.5-volt AA cells; (3) Zn-C 9-volt transistor batteries; (4) Hg 9-volt transistor batteries; (5) Alkaline 9-volt transistor batteries; (6) Ni-Cd 1.35-volt C cells; (7) Zn-C 1.5-volt C cells; (8) Alkaline 1.5-volt C cells; (9) Zn-C 1.5-volt D cells; (10) Alkaline 1.5-volt D cells; (11) Hg 1.35-volt D cells; and (12) Ni-Cd 1.35-volt D cells. Separate tests were conducted on batteries for their power output (voltage across a 2-ohm load) and their open circuit voltage using the following test method.

The power output of a fresh battery was sampled for approximately 20 milliseconds every second. This time limit was used to avoid excessive power drain on the batteries. The data for each battery tested was recorded on two channels of a strip-chart recorder to get data points ranging from several volts to 1 millivolt. A mark was then placed on the strip chart to indicate when the battery was immersed in the liquid nitrogen bath. The battery was monitored until it was again "live" after being removed from the liquid nitrogen bath. A battery was judged to be live by the same standards as a dead battery. However, the usefulness of information relative to the time required for the battery to become live is questionable since the batteries were not left in the bath long enough to reach equilibrium. The test was repeated with a new battery until four batteries of each type had been tested.

The method used to test the open circuit voltage was the same as the method used to test the power output, except the battery's voltage (input resistance of 1 megohm) was measured continuously by the strip-chart recorder.

RESULTS

The data for these battery types is shown in Tables 1 through 24 and Figures 1 through 12. A battery was considered dead if it produced 0.002 volts or less under a 2-ohm load or 0 volts under open circuit conditions.

All batteries recovered with no measurable effects upon being returned to room temperature. Batteries were considered live at the same voltages as the death condition.

CONCLUSIONS

The time to battery death appears to be more a function of the battery's mass than its chemical type or voltage. There is also a strong positive correlation between the length of time to die and the length of time to become live upon return to room temperature. Thus, the longer it takes to die, the longer it will also take to become live again.

RECOMMENDATIONS

Based on the data in Tables 1 through 24 it is recommended that a battery not be considered safe (dead) until it has been immersed in a liquid nitrogen bath for 15 minutes and that it be considered unsafe (live) after no more than 1 minute after being returned to room temperature (75° F).

TABLE 1
POWER OUTPUT OF ZN-C 1.5-VOLT AA CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.20	1.20	1.20	1.10
2.55	1.15	1.10	1.15	1.05
3.825	1.10	0.85	0.95	0.75
4.425	0.80	0.35	0.65	0.15
5.025	0.40	0.05	0.20	0.02
5.625	0.095	0.005	0.035	0
6.225	0.020	0	0.002	0
7.825	0.001	0	0	0

Arithmetic mean time to die = 6.625 seconds
Standard deviation = 0.632 second

When soaked for an average of 120 seconds, the batteries were live in a mean time of 255 seconds, with a standard deviation of 28.9 seconds.

TABLE 2
OPEN CIRCUIT VOLTAGE OF ZN-C 1.5-VOLT AA CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.5	1.5	1.5	1.5
7.0	1.5	1.5	0.8	1.3
9.0	0.75	1.5	0.025	0.10
10.0	0.2	1.5	0.008	0.025
11.0	0.014	1.5	0.003	0.008
12.0	0.002	1.5	0	0.003
13.0	0	1.5	0	0
14.0	0	1.4	0	0
15.0	0	1.0	0	0
16.0	0	0.021	0	0
17.0	0	0	0	0

Arithmetic mean time to die = 13.8 seconds
Standard deviation = 2.22 seconds

When soaked for an average of 131 seconds, the batteries were live in a mean time of 111 seconds, with a standard deviation of 36.4 seconds.

TABLE 3
POWER OUTPUT OF ALKALINE 1.5-VOLT AA CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.25	1.25	1.25	1.25
6.45	1.25	1.25	1.25	1.25
12.75	1.15	1.05	1.20	1.15
19.1	0.75	0.75	0.80	0.80
25.45	0.25	0.25	0.30	0.50
28.63	0.100	0.150	0.120	0.25
31.81	0.030	0.050	0.035	0.150
34.99	0.007	0.010	0.010	0.050
38.17	0	0.002	0	0.010
41.35	0	0	0	0.002

Arithmetic mean time to die = 38.97 seconds
Standard deviation = 1.25 seconds

When soaked for an average of 120 seconds, the batteries were live in a mean time of 261.3 seconds, with a standard deviation of 7.5 seconds.

TABLE 4
OPEN CIRCUIT VOLTAGE OF ALKALINE 1.5-VOLT AA CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.5	1.5	1.5	1.5
36.0	1.5	1.5	1.3	1.4
39.0	1.0	1.5	0.40	0.40
41.0	0.40	1.3	0.050	0.050
42.0	0.20	1.1	0.018	0.015
43.0	0.10	0.80	0.005	0.005
44.0	0.030	0.40	0.002	0.002
45.0	0.012	0.20	0.001	0.001
46.0	0.004	0.075	0	0
47.0	0.001	0.022	0	0
48.0	0	0.007	0	0
49.0	0	0.003	0	0
50.0	0	0.001	0	0
51.0	0	0	0	0

Arithmetic mean time to die = 47.8 seconds
Standard deviation = 2.36 seconds

When soaked for an average of 523 seconds, the batteries were live in a mean time of 114 seconds, with a standard deviation of 7.3 seconds.

TABLE 5
POWER OUTPUT OF ZN-C 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	2	3	4
0	3.0	3.5	3.5	3.5
12.75	2.5	3.5	3.5	3.0
25.5	2.0	3.0	3.0	3.0
31.875	1.0	2.5	3.0	2.5
36.975	0.050	2.5	3.0	2.5
42.075	0.010	2.0	2.5	1.5
47.175	0	1.5	2.0	0.5
52.275	0	0.75	1.5	0.150
57.375	0	0.5	0.5	0.015
62.475	0	0.085	0.095	0
65.025	0	0.045	0.045	0
70.125	0	0.025	0.020	0
75.225	0	0.010	0.005	0
80.325	0	0	0	0

Arithmetic mean time to die = 65.08 seconds
Standard deviation = 13.7 seconds

When soaked for an average of 180 seconds, the batteries were live in a mean time of 580.25 seconds, with a standard deviation of 86.8 seconds.

TABLE 6
OPEN CIRCUIT VOLTAGE OF ZN-C 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	2	3	4
0	9.5	9.6	9.7	9.6
50	9.5	9.4	9.5	9.6
55	9.5	9.1	9.4	9.6
60	9.5	7.8	9.2	9.6
65	9.4	3.1	7.6	9.5
70	8.8	0.20	2.0	9.4
75	7.0	0.008	0.10	8.9
80	2.9	0	0.003	6.9
85	0.42	0	0	2.2
90	0.05	0	0	0.20
95	0.006	0	0	0.007
100	0	0	0	0

Arithmetic mean time to die = 91.2 seconds
Standard deviation = 10.3 seconds

When soaked for an average of 348 seconds, the batteries were live in a mean time of 175 seconds, with a standard deviation of 16.56 seconds.

TABLE 7
POWER OUTPUT OF HG 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	2	3	4
0	1.3	0.7	1.2	0.8
10	1.0	0.55	1.0	0.50
14.8	0.80	0.40	0.80	0.38
20	0.40	0.05	0.41	0.20
25	0.20	0.017	0.25	0.10
28	0.19	0.003	0.20	0.080
29	0.0[illegible]0	0.001	0.180	0.050
35	0.026	0	0.050	0.020
38	0.007	0	0.027	0.009
40.4	0.002	0	0.015	0.005
41.6	0.001	0	0.011	0.004
44	0	0	0.004	0.001
47	0	0	0.001	0
50	0	0	0	0

Arithmetic mean time to die = 40.4 seconds
Standard deviation = 7.92 seconds

When soaked for an average of 180 seconds, the batteries were live in a mean time of 617 seconds, with a standard deviation of 139 seconds.

TABLE 8
OPEN CIRCUIT VOLTAGE OF HG 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	2	3	4
0	8.8	8.8	8.4	8.6
40	8.8	8.8	8.4	8.6
50	8.8	8.8	2.0	8.3
60	8.8	8.7	0	0.10
68	8.8	1.5	0	0
72	8.4	0.017	0	0
74	7.9	0.003	0	0
76	6.8	0	0	0
80	1.7	0	0	0
82	0.45	0	0	0
84	0.10	0	0	0
86	0.018	0	0	0
88	0.006	0	0	0
90	0.003	0	0	0
92	0	0	0	0

Arithmetic mean time to die = 73 seconds
Standard deviation = 14.6 seconds

When soaked for an average of 270 seconds, the batteries were live in a mean time of 163 seconds, with a standard deviation of 85 seconds.

TABLE 9
POWER OUTPUT OF ALKALINE 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	BATTERY 2	BATTERY 3	BATTERY 4
0	3.75	3.75	4.0	4.0
12.75	2.0	1.75	3.0	3.0
25.5	0.50	0.75	1.25	1.25
31.875	0.065	0.50	0.50	0.75
38.25	0	0.25	0.085	0.115
38.25	0	0.25	0.085	0.115
44.625	0	0.060	0.015	0.025
51	0	0.010	0	0
57.375	0	0	0	0

Arithmetic mean time to die = 49.4 seconds
Standard deviation = 7.92 seconds

When soaked for an average of 180 seconds, the batteries were live in a mean time of 720 seconds, with a standard deviation of 23.7 seconds.

TABLE 10
OPEN CIRCUIT VOLTAGE OF ALKALINE 9-VOLT TRANSISTOR BATTERIES

TIME (sec)	BATTERY 1	BATTERY 2	BATTERY 3	BATTERY 4
0	9.3	9.3	9.3	9.3
100	9.3	9.3	9.3	9.3
120	9.3	8.0	9.3	9.3
130	9.3	1.6	9.3	9.3
140	9.3	0.045	9.0	9.0
150	9.3	0.001	6.7	8.4
160	9.3	0	1.4	3.9
170	8.7	0	0.050	0.50
180	5.7	0	0.003	0.017
190	1.5	0	0	0.001
210	0.007	0	0	0
220	0	0	0	0

Arithmetic mean time to die = 188 seconds
Standard deviation = 29 seconds

When soaked for an average of 381 seconds, the batteries were live in a mean time of 44.5 seconds, with a standard deviation of 27.2 seconds.

TABLE 11
POWER OUTPUT OF NI-CD 1.35-VOLT C CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.1	1.0	1.1	1.05
6.7	0.8	1.0	1.1	1.05
21.2	0.7	0.95	0.90	0.88
40	0.63	0.94	0.90	0.82
80	0.70	0.90	0.88	0.82
90	0.70	0.80	0.78	0.82
101	0.60	0.60	0.35	0.80
105	0.60	0.12	0.24	0.78
110	0.40	0.12	0.04	0.70
120	0.10	0.025	0.001	0.50
130	0.008	0.001	0	0.10
135	0.001	0	0	0.050
140	0	0	0	0.015
145	0	0	0	0.004
150	0	0	0	0.001

Arithmetic mean time to die = 133.7 seconds
Standard deviation = 10.5 seconds

When soaked for an average of 205 seconds, the batteries were live in a mean time of 261 seconds, with a standard deviation of 10.4 seconds.

TABLE 12
OPEN CIRCUIT VOLTAGE OF NI-CD 1.35-VOLT C CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	1.10	1.30	1.30	1.05
145	1.10	1.30	1.30	1.05
155	1.05	1.30	1.30	1.05
165	0.75	1.255	1.30	1.05
170	0.10	1.25	1.30	1.05
175	0.028	1.00	1.30	1.05
180	0.001	0.50	1.30	1.05
185	0	0.10	1.30	1.05
190	0	0.017	1.255	1.05
195	0	0.001	1.20	1.05
200	0	0	0.90	1.05
205	0	0	0.35	1.05
210	0	0	0.05	1.05
215	0	0	0.006	1.05
220	0	0	0	1.05
290	0	0	0	1.05
295	0	0	0	1.00
305	0	0	0	0.85
315	0	0	0	0.65
320	0	0	0	0.45
325	0	0	0	0.25
330	0	0	0	0.10
335	0	0	0	0.05
340	0	0	0	0.022
345	0	0	0	0.009
350	0	0	0	0.004
355	0	0	0	0

Arithmetic mean time to die = 240 seconds
Standard deviation = 78.6 seconds

When soaked for an average of 427 seconds, the batteries were live in a mean time of 209 seconds, with a standard deviation of 52.4 seconds.

TABLE 13
POWER OUTPUT OF ZN-C 1.5-VOLT C CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	1.1	1.05	1.1	1.05
10	1.0	0.90	1.05	1.0
30	0.92	0.81	0.90	0.90
60	0.80	0.74	0.80	0.80
70	0.70	0.68	0.70	0.65
80	0.58	0.60	0.60	0.63
85	0.48	0.51	0.52	0.60
90	0.39	0.49	0.45	0.50
100	0.25	0.33	0.30	0.38
110	0.12	0.20	0.18	0.20
120	0.07	0.10	0.09	0.10
130	0.023	0.05	0.04	0.06
140	0.011	0.024	0.021	0.03
150	0.005	0.011	0.009	0.013
160	0.002	0.006	0.004	0.006
170	0.001	0.003	0.002	0.002
180	0	0.001	0.001	0.001
190	0	0	0	0

Arithmetic mean time to die = 187.5 seconds
Standard deviation = 5 seconds

When soaked for an average of 326.5 seconds, the batteries were live in a mean time of 369 seconds, with a standard deviation of 6 seconds.

TABLE 14
OPEN CIRCUIT VOLTAGE OF ZN-C 1.5-VOLT C CELLS

TIME (sec)	BATTERY 1	BATTERY 2	BATTERY 3	BATTERY 4
0	1.55	1.55	1.55	1.55
40	1.55	1.55	1.55	1.55
65	1.50	1.50	1.50	1.50
100	1.40	1.40	1.40	1.40
125	1.30	1.35	1.25	1.30
135	1.15	1.15	1.10	1.20
145	0.80	0.75	0.30	0.75
155	0.25	0.20	0.10	0.15
165	0.045	0.025	0.012	0.022
175	0.006	0.002	0.002	0.002
185	0	0	0	0

Arithmetic mean time to die = 185 seconds
Standard deviation = 0 seconds

When soaked for an average of 357.8 seconds, the batteries were live in a mean time of 228.5 seconds, with a standard deviation of 5.8 seconds.

TABLE 15
POWER OUTPUT OF ALKALINE 1.5-VOLT C CELLS

TIME (sec)	BATTERY 1	BATTERY 2	BATTERY 3	BATTERY 4
0	1.5	1.5	1.5	1.5
5	1.10	1.10	1.05	1.13
10	1.05	1.07	1.04	0.95
15	0.93	1.00	0.98	0.85
20	0.83	0.90	0.85	0.77
25	0.67	0.73	0.65	0.57
30	0.50	0.55	0.44	0.35
35	0.25	0.32	0.20	0.15
40	0.09	0.15	0.06	0.045
45	0.022	0.050	0.016	0.010
50	0.004	0.014	0.003	0.018
55	0	0.003	0	0
60	0	0	0	0

Arithmetic mean time to die = 55 seconds
Standard deviation = 5 seconds

When soaked for an average of 228.3 seconds, the batteries were live in a mean time of 468.5 seconds, with a standard deviation of 18.9 seconds.

TABLE 16
OPEN CIRCUIT VOLTAGE OF ALKALINE 1.5-VOLT C CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	1.55	1.55	1.55	1.55
55	1.55	1.55	1.55	1.55
65	1.50	1.45	0.003	0.50
75	0.20	0	0	0.0005
80	0.007	0	0	0
85	0	0	0	0

Arithmetic mean time to die = 78.8 seconds
Standard deviation = 7.2 seconds

When soaked for an average of 260.2 seconds, the batteries were live in a mean time of 251.3 seconds, with a standard deviation of 24.5 seconds.

TABLE 17
POWER OUTPUT OF ZN-C 1.5-VOLT D CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	1.1	1.05	1.15	1.15
25	1.05	1.03	1.10	1.10
50	0.95	0.95	1.0	0.99
60	0.85	0.87	0.92	0.88
70	0.75	0.77	0.80	0.75
80	0.65	0.65	0.65	0.62
90	0.50	0.50	0.48	0.37
100	0.35	0.35	0.30	0.20
110	0.20	0.19	0.15	0.10
120	0.10	0.090	0.080	0.040
130	0.042	0.045	0.029	0.015
140	0.018	0.021	0.021	0.006
150	0.008	0.010	0.006	0.003
160	0.004	0.005	0.003	0.001
170	0.002	0.0022	0.001	0
180	0.0009	0.0008	0	0
190	0	0	0	0

Arithmetic mean time to die = 170 seconds
Standard deviation = 8.2 seconds

When soaked for an average of 447 seconds, the batteries were live in a mean time of 828 seconds, with a standard deviation of 30.6 seconds.

TABLE 18
OPEN CIRCUIT VOLTAGE OF ZN-C 1.5-VOLT D CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.65	1.65	1.65	1.65
50	1.62	1.62	1.62	1.65
100	1.60	1.60	1.55	1.60
120	1.55	1.55	1.54	1.57
140	1.50	1.50	1.52	1.55
160	1.45	1.45	1.50	1.50
180	1.30	1.35	1.45	1.40
200	0.90	1.00	1.15	1.05
220	0.45	0.55	0.50	0.55
240	0.014	0.021	0.070	0.022
260	0	0.0008	0.003	0.001
280	0	0	0	0

Arithmetic mean time to die = 265 seconds
Standard deviation = 10 seconds

When soaked for an average of 418.7 seconds, the batteries were live in a mean time of 287.5 seconds, with a standard deviation of 15.5 seconds.

TABLE 19
POWER OUTPUT OF ALKALINE 1.5-VOLT D CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.25	1.20	1.20	1.15
10	1.10	1.00	1.19	1.08
20	0.95	0.99	1.08	1.00
30	0.70	0.90	0.80	0.90
35	0.45	0.85	0.60	0.80
40	0.20	0.73	0.30	0.65
45	0.070	0.60	0.100	0.45
50	0.021	0.40	0.030	0.30
55	0.004	0.25	0.005	0.12
60	0.0005	0.10	0.002	0.05
65	0	0.06	0	0.020
70	0	0.022	0	0.006
75	0	0.007	0	0.0015
80	0	0.002	0	0
85	0	0	0	0

Arithmetic mean time to die = 68.8 seconds
Standard deviation = 10.3 seconds

When soaked for an average of 162 seconds, the batteries were live in a mean time of 394.8 seconds, with a standard deviation of 112.8 seconds.

TABLE 20
OPEN CIRCUIT VOLTAGE OF ALKALINE 1.5-VOLT D CELLS

TIME (sec)	BATTERY 1	BATTERY 2	BATTERY 3	BATTERY 4
0	1.55	1.55	1.50	1.50
50	1.55	1.55	1.50	1.50
60	1.55	1.55	1.50	1.50
70	1.55	1.00	1.50	1.50
75	1.55	0.17	1.50	1.50
80	1.55	0.060	1.50	1.50
85	1.55	0	1.50	1.50
90	1.55	0	1.50	1.50
95	1.55	0	1.50	1.50
100	1.53	0	1.40	1.47
105	1.50	0	1.25	1.40
110	1.30	0	0.75	1.15
115	0.75	0	0.20	0.65
120	0.20	0	0.026	0.20
125	0.011	0	0.003	0.020
130	0.002	0	0	0.002
135	0	0	0	0

Arithmetic mean time to die = 118.8 seconds
Standard deviation = 22.5 seconds

When soaked for an average of 288.8 seconds, the batteries were live in a mean time of 320.5 seconds, with a standard deviation of 7.4 seconds.

TABLE 21
POWER OUTPUT OF Hg 1.35-VOLT D CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	0.98	0.98	0.98	1.00
50	0.90	0.86	0.88	0.90
60	0.85	0.76	0.78	0.82
70	0.76	0.69	0.74	0.75
80	0.68	0.62	0.68	0.68
90	0.65	0.52	0.62	0.56
100	0.58	0.40	0.52	0.45
110	0.48	0.28	0.40	0.30
120	0.36	0.16	0.26	0.19
130	0.24	0.08	0.20	0.10
140	0.15	0.027	0.060	0.025
150	0.037	0.009	0.022	0.008
160	0.015	0.002	0.006	0.002
170	0.004	0	0.001	0
180	0.001	0	0	0
190	0	0	0	0

Arithmetic mean time to die = 167.5 seconds
Standard deviation = 9.6 seconds

When soaked for an average of 423.8 seconds, the batteries were live in a mean time of 677.5 seconds, with a standard deviation of 74.2 seconds.

TABLE 22
OPEN CIRCUIT VOLTAGE OF Hg 1.35-VOLT D CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.65	1.60	1.60	1.65
100	1.65	1.60	1.65	1.65
180	1.60	1.60	1.65	1.60
185	1.57	1.55	1.62	1.57
190	1.55	1.55	1.60	1.50
195	1.50	1.47	1.55	1.10
200	1.05	1.05	1.15	0.75
205	0.73	0.75	0.80	0.45
210	0.35	0.35	0.40	0.10
215	0.10	0.10	0.15	0.023
220	0.022	0.012	0.023	0.005
225	0.005	0.002	0.006	0.001
230	0.001	0	0.001	0
235	0	0	0	0

Arithmetic mean time to die = 227.5 seconds
Standard deviation = 2.9 seconds

When soaked for an average of 420.5 seconds, the batteries were live in a mean time of 421.2 seconds, with a standard deviation of 12.8 seconds.

TABLE 23
POWER OUTPUT OF NI-CD 1.35-VOLT D CELLS

TIME (sec)	BATTERY 1	2	3	4
0	1.05	1.05	1.10	1.10
100	1.05	1.04	1.10	1.10
160	0.93	0.95	1.03	1.10
180	0.60	0.55	0.84	1.05
190	0.28	0.24	0.54	1.05
200	0.10	0.05	0.21	1.00
210	0.011	0.010	0.045	0.98
215	0.004	0.0038	0.015	0.95
220	0	0	0.005	0.92
240	0	0	0	0.72
260	0	0	0	0.26
270	0	0	0	0.060
280	0	0	0	0.012
285	0	0	0	0.004
290	0	0	0	0.0018

Arithmetic mean time to die = 242.5 seconds
Standard deviation = 43.9 seconds

When soaked for an average of 453 seconds, the batteries were live in a mean time of 1027.5 seconds, with a standard deviation of 37.5 seconds.

TABLE 24
OPEN CIRCUIT VOLTAGE OF NI-CD 1.35-VOLT D CELLS

TIME (sec)	BATTERY			
	1	2	3	4
0	1.26	1.26	1.26	1.25
200	1.26	1.25	1.26	1.25
250	1.26	1.00	1.26	1.25
260	1.26	0.60	1.26	1.25
270	1.26	0.08	1.25	1.25
280	1.26	0.027	1.10	1.25
290	1.25	0.010	0.65	1.25
300	1.10	0.004	0.30	1.25
310	0.72	0.001	0.14	1.10
320	0.52	0	0.05	0.67
330	0.10	0	0.026	0.25
340	0.035	0	0.010	0.10
350	0.014	0	0.005	0.045
360	0.007	0	0.002	0.020
370	0.004	0	0	0.010
380	0.001	0	0	0.006
390	0	0	0	0.002
400	0	0	0	0

Arithmetic mean time to die = 370 seconds
Standard deviation = 35.6 seconds

When soaked for an average of 492.5 seconds, the batteries were live in a mean time of 225 seconds, with a standard deviation of 32.7 seconds.

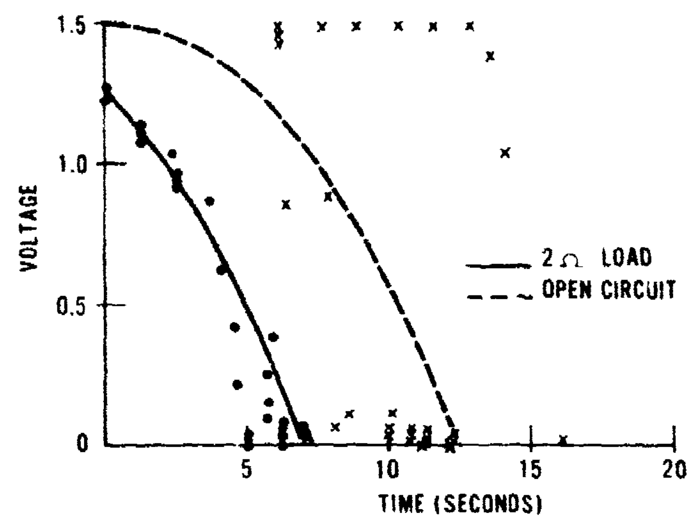

Figure 1. Zn-C 1.5-Volt AA Cells

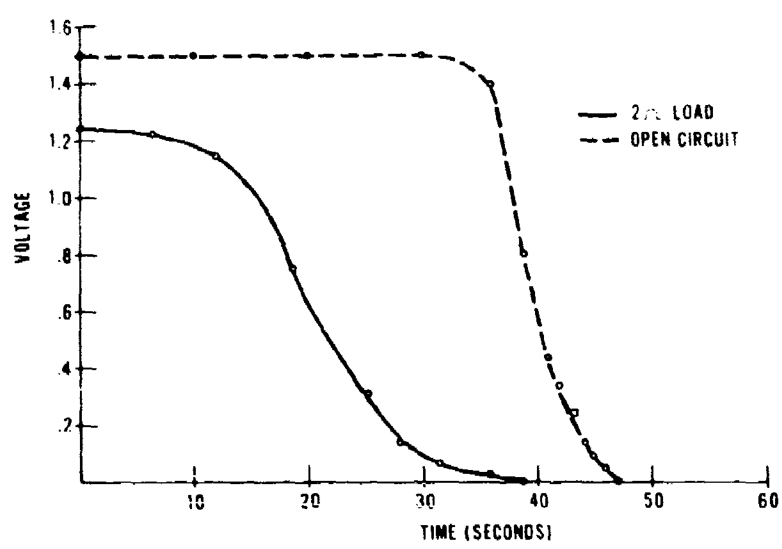

Figure 2. Alkaline 1.5-Volt AA Cells

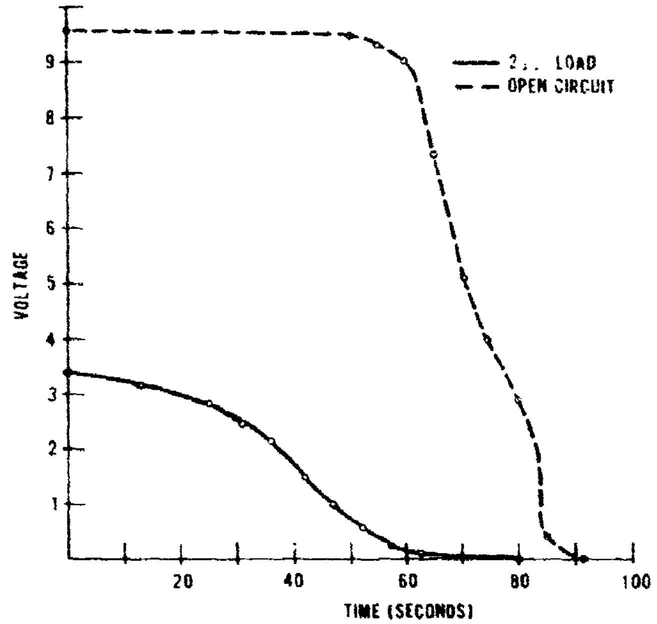

Figure 3. Zn-C 9-Volt Transistor Batteries

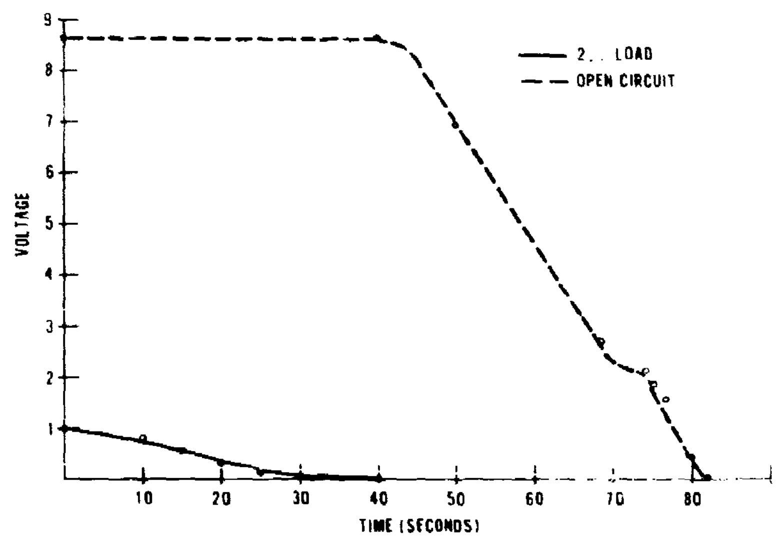

Figure 4. Hg 9-Volt Transistor Batteries

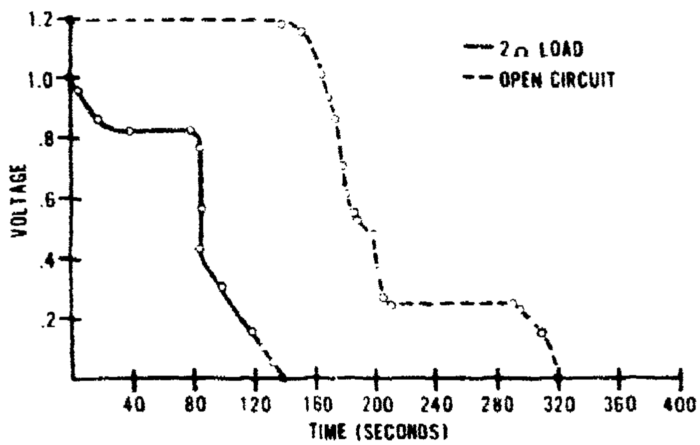

Figure 5. Alkaline 9-Volt Transistor Batteries

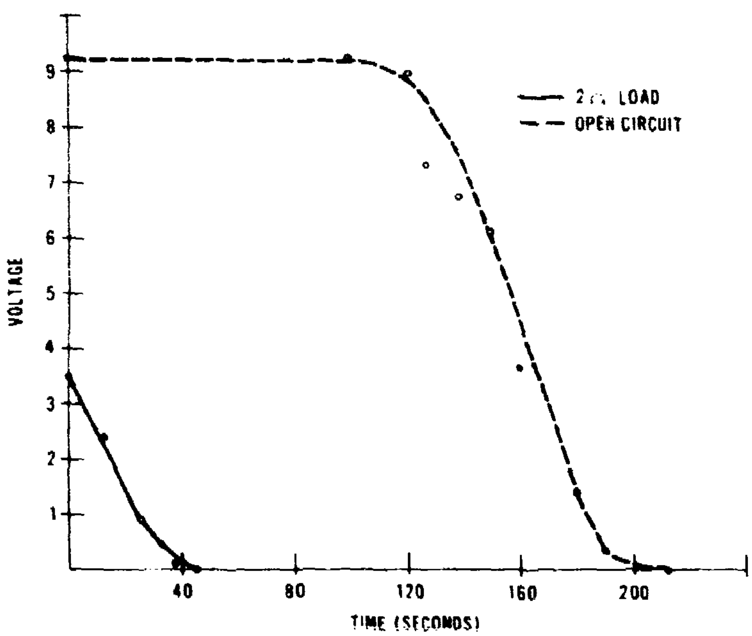

Figure 6. Ni-Cd 1.35-Volt C Cells

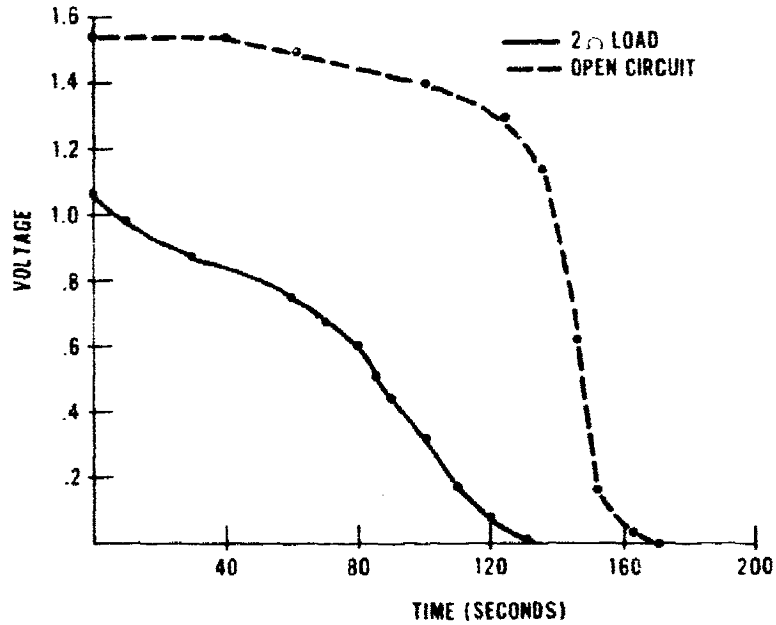

Figure 7. Zn-C 1.5-Volt C Cells

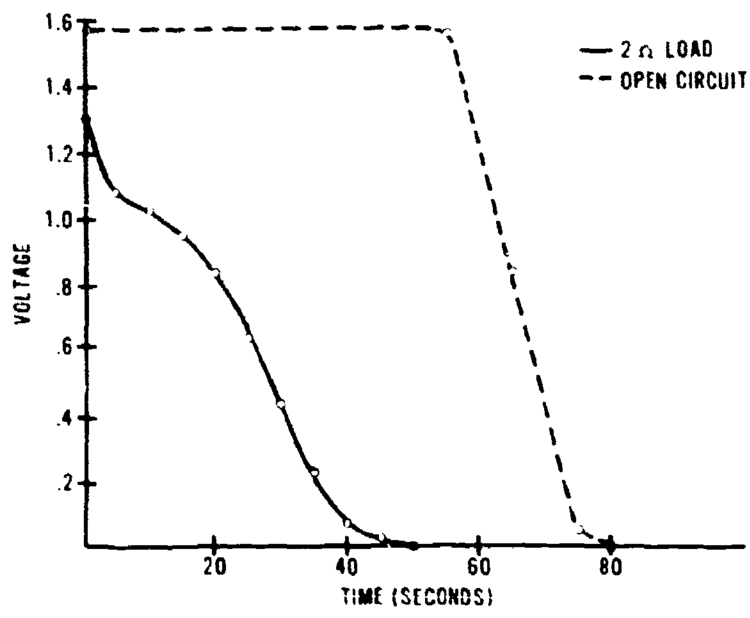

Figure 8. Alkaline 1.5-Volt C Cells

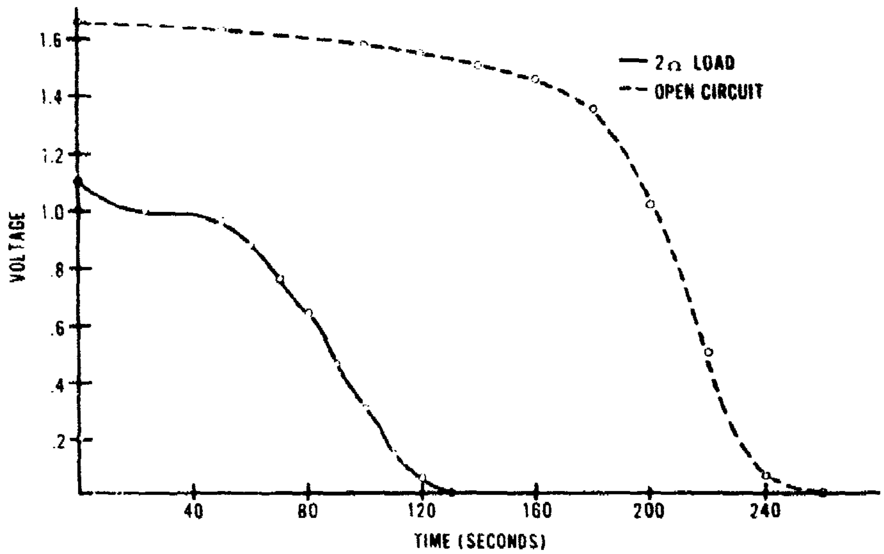

Figure 9. Zn-C 1.5-Volt D Cells

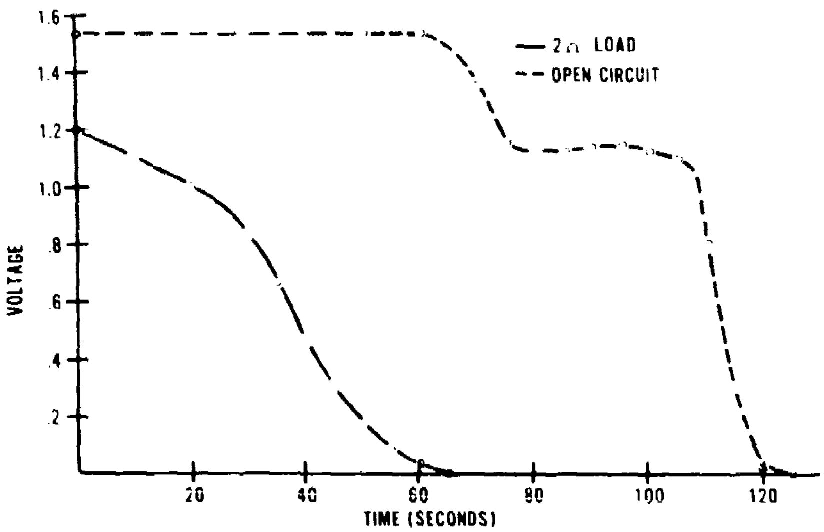

Figure 10. Alkaline 1.5-Volt D Cells

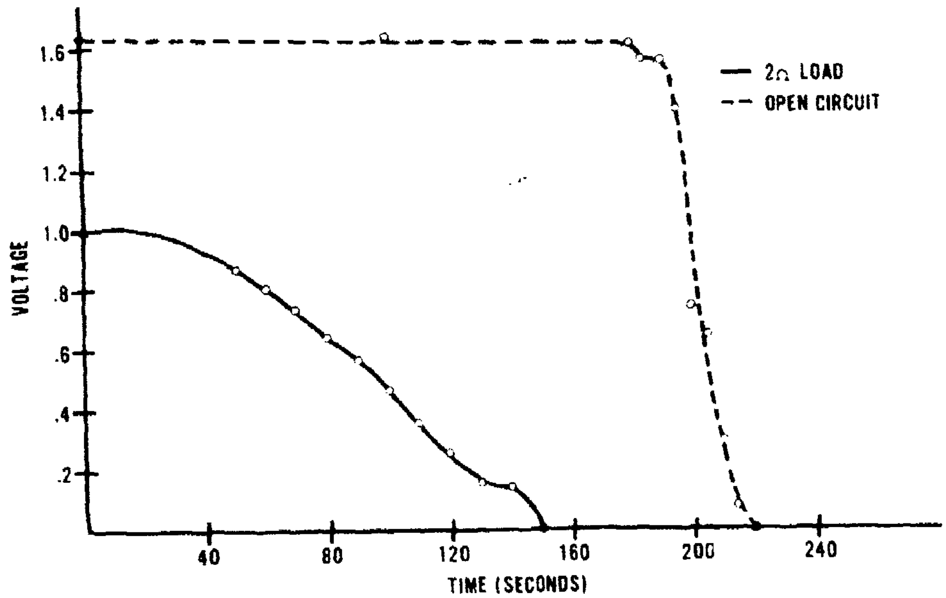

Figure 11. Hg 1.35-Volt D Cells

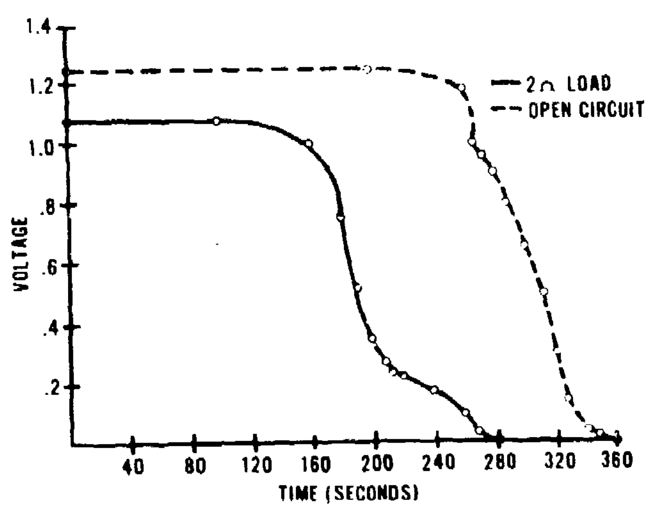

Figure 12. Ni Cd 1.35-Volt D Cells

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Many Improvised Explosive Devices (IED's) are fired by discharging electricity from a battery directly into an electric detonator. The purpose of this study was to determine if one possible method for defeating these type IED's would be to cool the batteries to cryogenic temperatures. Only those batteries readily available to the general public were investigated.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Cryogenics 2. Electric Batteries 3. Improvised Explosive Devices 4. Explosive Ordnance Disposal 5. Tools						